

Microcontrollers as a Tool for an Interdisciplinary Approach in Education

Jana Depešová¹, Adam Lednár²

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Abstract

Interdisciplinary education is an approach that integrates knowledge from various scientific fields into a unified and practically applicable framework. Currently, this concept is primarily realised through the STEM (Science, Technology, Engineering, and Mathematics) framework. STEM emphasises the integration of the natural sciences, engineering, technology, and mathematics, thereby creating the necessary conditions for developing critical thinking, problem-solving, and creativity. Unlike traditional curricular approaches, STEM does not present disciplines in isolation but strives for a synergistic connection between them. This creates a system that is more accessible to students and more closely aligned with real-world scenarios. Interdisciplinary education significantly contributes to the development of those 21st-century competences essential for the modern era. These include the ability to utilise modern technologies, apply theoretical knowledge in practice, and flexibly synthesise information from disparate areas. As an educational tool, microcontrollers represent a technological platform that supports the implementation of this interdisciplinary approach; they are utilised in projects that combine elements of computer science, physics, mathematics, and technology. This article examines their integration into teaching and the potential for connecting theory with practice through experimental and experiential learning.

Keywords: STEM Education, Microcontrollers, Interdisciplinary Learning

1 Introduction

The integration of microcontrollers into the educational process represents a contemporary approach to teaching technical and scientific subjects, with a particular emphasis on creativity,

¹ Constantine the Philosopher University in Nitra, Faculty of Education, Department of Technology and Information Technologies, Drážovská 4, 949 01 Nitra, Slovak Republic.
E-Mail: jdepesova@ukf.sk

² Constantine the Philosopher University in Nitra, Faculty of Education, Department of Technology and Information Technologies, Drážovská 4, 949 01 Nitra, Slovak Republic.
E-Mail: adam.lednar@ukf.sk

experimentation, and interdisciplinary learning. Traditional educational systems frequently compartmentalise disciplines such as physics, computer science, and technology; this tends to limit pupils' ability to synthesise theoretical knowledge with practical experience. The inclusion of microcontrollers, such as Arduino or the BBC micro:bit, into the curriculum addresses this challenge by facilitating experiential learning. This approach encourages pupils to develop independent thinking, enhances their problem-solving skills, and enables the application of knowledge within real-world situations.

2 Interdisciplinarity

Interdisciplinary thinking is the ability to integrate the knowledge and ways of thinking of two or more disciplines in order to achieve cognitive progress in ways that would be impossible or unlikely using only a single disciplinary approach (Mansilla, 2005, pp. 14–21; Mansilla & Duraising, 2007, pp. 215–237; Spelt et al., 2009, pp. 365–378). Thinking from the perspective of different disciplines helps to understand everyday experiences, such as sustainability issues (Bestelmeyer et al., 2015, pp. 37–43).

Interdisciplinary thinking leads to more complex, sophisticated, and advanced understanding. To facilitate the development of interdisciplinary thinking, interdisciplinary learning opportunities are needed. Students need support in synthesising two or more disciplines (Glancy & Moore, 2013, pp. 2–10; Spelt et al., 2009, pp. 365–378).

Looking for connections, identifying common features, and evaluating different methods, assumptions, and values from each discipline builds interdisciplinary thinking (Hursh et al., 1983, pp. 42–59).

Spelt et al. (2009, pp. 365–378) identified six conditions of the learning process that enable interdisciplinary thinking. The first four conditions are gradual progress, linearity, interactivity, and milestones with questions that support the development of interdisciplinary thinking. The remaining conditions focus on achieving interdisciplinarity and reflection. STEM education (science, technology, engineering, and mathematics) is a well-known example of interdisciplinary education that removes barriers between disciplines (Sahin, 2015, pp. 3–14; Vasquez et al., 2013, pp. 3–8).

By integrating disciplines, STEM education provides opportunities to learn and solve relevant real-world problems (Bybee, 2013, pp. 1–12; English, 2016, pp. 1–8). STEM education thus facilitates the building of interdisciplinary thinking. In the last two decades, STEM education has attracted the attention of many education systems. However, due to the rapid spread and growth of STEM education, its definition has changed over time. STEM education is not a clearly defined field, unlike scientific disciplines such as physics, biology, chemistry, mathematics, and computer science (Li et al., 2019, pp. 1–13).

Hasanah describes four definitions of STEM: as a discipline, as teaching, as a field, and as a career (Hasanah, 2020, pp. 2–10). The acronym STEM is used as a label for any event, programme, or activity that involves one or a combination of the four STEM disciplines, which leads to ambiguity and a lack of substantive meaning (Bybee, 2013, pp. 1–12; Vasquez et al., 2013, pp. 3–8). The acronym STEM has been expanded to include other disciplines and emphases, such as STEAM (“A” for arts) and STREAM (“R” for reading and writing) (Tan & Kidman, 2021, pp. 24–52). There are different interpretations of the integration of STEM disciplines, with many advocating disciplinary integrations to equip students with the skills needed to solve multidisciplinary problems. Others express scepticism due to insufficient content coverage and limited conceptual development (English et al., 2016, pp. 1–8). In recent years, a new term, STEAM, has been introduced, which includes the arts in these areas (Cook, 2016, pp. 11–12; Land, 2013, pp. 547–552).

Many ways of achieving this have been proposed (Henriksen, 2014, pp. 1–5), for example, using artistic design in project-based learning scenarios (Connor et al., 2015, pp. 37–47). Studies show that the use of artistic elements in the teaching of STEM disciplines can lead to increased student creativity (Marmon, 2019, pp. 3–10; Zhanova, 2019, pp. 2–12), although it is unclear to what extent this is due to the arts and to what extent to the multidisciplinary nature of STEM disciplines in general, as shown by Aguilera and Ortiz-Revilla (2021).

Assessment practices therefore play a key role in STEM education reform. However, when implementing STEM education to support innovation and improve teaching methods, certain challenges may arise. These challenges stem mainly from teachers’ personal characteristics and experiences, which may affect their openness to new teaching methods (Al Salami et al., 2017, pp. 63–88; Lin et al., 2022, pp. 24–52).

For example, male teachers may be more inclined to adopt STEM pedagogical methods, while female teachers may be more inclined to adhere to traditional teaching approaches (Hernández & Muñoz, 2020, pp. 369–386).

This may be due to the influence of gender on teachers’ beliefs and attitudes toward teaching, or it may be related to sociocultural factors. In addition, the subject that teachers teach may affect their openness to new teaching techniques. For example, science and technical subject teachers may more easily understand and accept the concepts and methods of STEM education, while humanities teachers may perceive them as unfamiliar or confusing (Smith et al., 2015, pp. 182–201).

Some related studies have found that STEM education may not have a significant impact on innovation and the improvement of teachers’ pedagogical methods. For instance, even though teachers completed training in STEM education, no significant changes or improvements were observed in their subsequent teaching practices. These findings suggest that in the process of implementing STEM education to promote innovation and improve teaching approaches, we must fully take these factors into account and seek appropriate strategies to overcome the related challenges (Brown et al., 2019, pp. 1–12).

2.1 Virtual laboratories

The efficacy of virtual laboratories within STEM education has been validated by numerous scientific studies. For instance, Lynch and Ghergulescu observed that such environments provide pupils with valuable opportunities to conduct experiments at their own pace within a controlled setting, while simultaneously addressing resource limitations, safety concerns, and geographical constraints. These authors identified several key benefits, including the provision of immediate feedback for pupils, opportunities for inquiry-based learning, and the elimination of hazards inherent in physical laboratories. Furthermore, the effectiveness of these simulations in supporting pupils' learning is well-documented; their research particularly highlights the pedagogical value of virtual laboratories when they are integrated into a broader educational framework that aligns virtual experiences with specific learning objectives and assessment strategies.

2.2 Online platforms for education

Similarly, platforms such as Tinkercad, Arduino, and the BBC micro:bit emerge as effective and accessible tools within STEM education. Tinkercad has proven particularly valuable for teaching electronics and circuit design. In a comparative study of interfaces for learning circuitry and coding with Arduino, Tselegkaridis, Sapounidis, and Papakostas observed that pupils utilising a graphical user interface (GUI), such as Tinkercad, reported a more profound understanding of how components within microcontroller circuits are interconnected. The intuitive, visual nature of the Tinkercad environment appears to foster a conceptual understanding of complex electronic systems.

The Arduino platform is becoming increasingly common in STEM education as an accessible and versatile tool for teaching electronics, programming and design principles. Compared to alternatives, the Arduino platform offers excellent technical capabilities; initially, fewer educational resources were available, but this gap has increasingly been addressed in recent years. Several studies have examined the specific educational benefits of Arduino-based learning. Chaudry used Arduino Uno microcontrollers as an extra-credit activity in undergraduate physics courses and recorded increased student interest in physics and a better understanding of fundamental physics concepts (Marzoli et al., 2021, pp. 364–378).

The BBC micro:bit platform is particularly well-suited for beginners, owing to its inherent simplicity and ease of use. This underscores the necessity of selecting appropriate technologies based on pupils' level of experience and specific educational requirements. Furthermore, the financial cost of procuring laboratory kits equipped with microcontrollers remains a significant barrier to the adoption of these teaching resources. This fundamental issue, as reported by Hsiung et al. (2010), prompted the development of a cost-effective

microcontroller trainer that pupils can retain, thereby enhancing their learning experience. This strategy successfully addressed challenges within microcontroller-related courses delivered via both distance education and campus-based formats by bypassing typical institutional budget constraints. Ultimately, the use of such training kits is indispensable for the study of microcontroller systems and embedded-systems technology.

Theoretical knowledge alone is insufficient to consolidate concepts within electronics and embedded systems education. Simulation kits offer a cost-effective solution for enhancing educational outcomes. It is essential that pupils are able to translate classroom theory into tangible applications through the development of physical devices. The factors outlined in the introduction of this paper informed the focus of our research, which analyses findings related to the integration of microcontrollers into teaching. The research problem was specifically defined to be addressed through an analysis of the responses to the following research questions:

Research questions (RQ)

RQ1: Does the use of microcontrollers affect students' achievement?

RQ2: Does working with microcontrollers support understanding of interdisciplinary relationships?

RQ3: Does students' attitude toward STEM subjects change after activities involving microcontrollers?

RQ4: Do students perceive working with microcontrollers as more engaging than traditional teaching?

RQ5: Do the results differ between groups of students with different forms of instruction?

RQ6: Does the integration of microcontrollers influence students' problem-solving skills?

RQ7: What is the impact on students' motivation to continue in STEM fields?

RQ8: Does teamwork improve when working with microcontrollers?

Hypotheses (H)

H1: The intervention will improve the understanding of interdisciplinary relationships.

H2: Students in the experimental group will perceive the instruction more positively.

H3: The results of the groups will differ statistically significantly.

H4: Microcontrollers will support the development of problem-solving skills.

H5: After the activity, interest in further study in the STEM field will increase.

H6: Microcontrollers will improve students' collaboration in a team.

Based on the research results of other authors, we created an initial database of information necessary for carrying out research focused on examining the integration of microcontrollers as a tool for an interdisciplinary approach in education.

Authors who have addressed this issue:

- Šebo, M., et al. (2023): *Microcontrollers in interdisciplinary education*. KEGA project no. 019UKF-4/2023.
- Krajinčák, E. (2021): *Technical education at secondary schools in an online environment*.
- Krajinčák, E. (2022): *Distance education in the training of technical subject teachers at primary and secondary schools with a specific focus on electrical engineering*.
- Bellová, R. (2021): *An interdisciplinary approach to science education in the context of Slovak schools*.
- Akis, A. P., et al. (2024): *Using Arduino in Science, Technology, Engineering, and Mathematics (STEM) Education: Bibliometric Analysis*.
- Sulimro, F. L., et al. (2023): *Arduino Microcontroller Boards in Digital Learning for Science and STEM Education*.
- Guarda, G. F. (2023): *A systematic review of the use of BBC Micro:bit in K-12 education*.
- Filipe, J., et al. (2024): *Integrated STEAM education for student creativity: iSTEAM educational sequence*.
- Kefalis, C., et al. (2025): *Hands-on STEM learning experiences using digital fabrication technologies*.

We provide more detailed information from selected published studies by these authors, which we compared in terms of their aim, methodology, research sample, and the contribution of the implemented experiments.

A. P. Akis, et al. (2024)

Aim: To examine *Using Arduino in Science, Technology, Engineering, and Mathematics (STEM) Education: Bibliometric Analysis*. **Methodology:** Bibliometric analysis. **Sample/scope:** Analysis of publications over a defined period (hosted in databases such as Scopus/Web of Science). **Key findings:** Arduino has strong potential in STEM activities; limited international cooperation; increasing number of publications. **Strengths:** Relevance for school practice, open access (where available), clear recommendations for implementation. **Weaknesses:** Sometimes limited sample sizes, short-term measurements, few longitudinal studies.

F. L. Sulimro et al. (2023)

Aim: To examine *Arduino Microcontroller Boards in Digital Learning for Science and STEM Education: A Bibliometric Analysis (2012–2022)*. **Methodology:** Bibliometric analysis. **Sample/scope:** Analysis of publications over a defined period (hosted in databases such as Scopus/Web of Science). **Key findings:** Mapped trends and hot topics; growing use of digital learning; significant role of Arduino in maker education. **Strengths:** Relevance for school practice, open access (where available), clear recommendations for implementation.

Weaknesses: Sometimes limited sample sizes, short-term measurements, few longitudinal studies.

G. F. Guarda (2023)

Aim: To examine a systematic review of the use of BBC Micro:bit in K–12 education.

Methodology: Systematic review. **Sample/scope:** Systematic review of selected studies with a synthesis of findings and gaps. **Key findings:** Micro:bit is used in science and computing; affordable and easy to use; gaps in longitudinal impact studies. **Strengths:** Relevance for school practice, open access (where available), clear recommendations for implementation.

Weaknesses: Sometimes limited sample sizes, short-term measurements, few longitudinal studies.

J. Filipe, et al. (2024)

Aim: To examine integrated STEAM education for student creativity: the iSTEAM educational sequence. **Methodology:** Empirical study (intervention) (see source). **Sample/scope:**

Intervention or case study with specific classes/tasks (see original article for methodological details). **Key findings:** iSTEAM sequences improved creativity and engagement of 9th- and 10th-grade students; practical design-focused tasks are effective. **Strengths:** Relevance for school practice, open access (where available), clear recommendations for implementation.

Weaknesses: Sometimes limited sample sizes, short-term measurements, few longitudinal studies.

C. Kefalis et al. (2025)

Aim: To examine hands-on STEM learning experiences using digital fabrication technologies.

Methodology: Empirical/case study. **Sample/scope:** Intervention or case study with specific classes/tasks. **Key findings:** Digital fabrication (FabLab) with microcontrollers supports situated STEM learning and skills development. **Strengths:** Relevance for school practice, open access (where available), clear recommendations for implementation. **Weaknesses:**

Sometimes limited sample sizes, short-term measurements, few longitudinal studies.

E. Krajinčák (2024)

Aim: To examine the effectiveness and possibilities of technical education at secondary schools in an online environment. **Methodology:** Research based on questionnaires, analysis of distance-learning activities, and observation. **Sample/scope:** Students and teachers of technical subjects at selected secondary schools during the period of online teaching (2021–2023). **Key findings:** Online technical education is feasible with the use of digital tools and virtual laboratories; the greatest benefit is found in blended (hybrid) forms of instruction.

Strengths: Current research clearly focused on practice; identifies real problems faced by teachers; empirical data from Slovak schools. **Weaknesses:** Limited sample size and duration of the experiment; results are not directly comparable with foreign meta-analyses.

E. Krajinčák (2022)

Aim: To examine the possibilities of distance education in the training of technical subject teachers with a focus on electrical engineering. **Methodology:** Qualitative analysis and model design of a distance-teaching system with testing of selected modules in practice. **Sample/scope:** Students of teacher-education programmes with a technical focus at the Faculty of Education, UKF; pilot verification within specialised subjects. **Key findings:** Distance education is effective when the content structure is clear and technical tools are available; it supports the development of digital literacy in future teachers. **Strengths:** Relevant topic; methodological support for the education of technical subject teachers; practical applicability for teaching practice. **Weaknesses:** Smaller sample of respondents; absence of quantitative measurements of skills effectiveness.

R. Bellová (2021)

Aim: To examine the level of interdisciplinarity in science education in the context of Slovak schools. **Methodology:** Empirical study based on a questionnaire survey of primary and secondary school teachers. **Sample/scope:** Teachers of science subjects (physics, biology, chemistry) at primary and secondary schools; approximately 200 respondents. **Key findings:** Teachers support an interdisciplinary approach but face a lack of methodological materials and time demands in teaching. **Strengths:** Real data from the Slovak context; clear identification of teachers' needs and barriers to interdisciplinarity. **Weaknesses:** Questionnaire survey without verification in practice; no experimental verification of effects.

M. Šebo et al. (2023) – KEGA project no. 019UKF-4/2023

Aim: To implement microcontrollers into teaching at primary and secondary schools in order to support interdisciplinary learning. **Methodology:** Applied research project; development of teaching aids, methodological materials and e-learning, verification in schools. **Sample/scope:** Primary and secondary schools involved in the project; teachers of technical and science subjects. **Key findings:** The use of microcontrollers increases students' motivation and enables the integration of physics, informatics, and technology; confirms the effectiveness of project-based learning. **Strengths:** Direct practical impact, up-to-date topic, interdisciplinary integration; creation of methodological outputs for practice. **Weaknesses:** Results are still interim; no published large-scale analysis of effectiveness yet.

3 Analysis and Interpretation of Results

Through the rigorous processing, examination, and analysis of the results, several graphical representations were developed; these allow the findings from the cited literature to be interpreted in the context of integrating microcontrollers into education. The presented graphs facilitate a comparison between groups of pupils, an assessment of the time demands associated with specific tasks, and an evaluation of pupils' knowledge levels and attitudes

towards working with microcontrollers. These data provide a concise synthesis of the findings, derived directly from the values illustrated in the referenced figures.

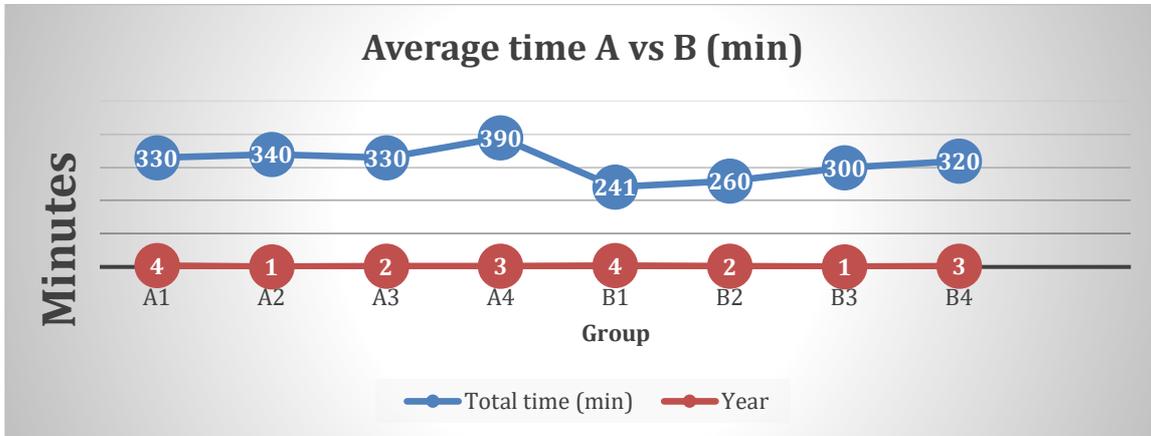


Figure 1: Average time A vs B. Source: Krajinčák E 2024.

The graph illustrates the duration of task completion across the individual groups. From the values presented, it is evident that Group A completed the experiments in an average of 347 minutes, whereas Group B achieved a lower average of 280 minutes. This 67-minute disparity suggests higher efficiency within Group B, which operated under a different instructional framework. The range of values within Group A (330–390 min) indicates greater variability in the working pace; conversely, Group B demonstrated more consistent performance (241–320 min). These data confirm that the organisation of teaching and the methodology of task implementation significantly influence the time demands of the experiments.

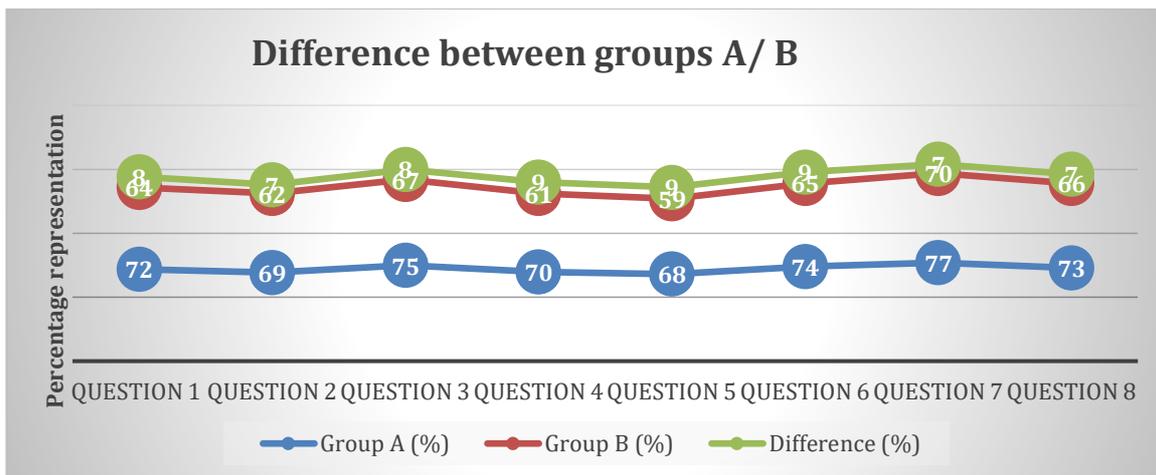


Figure 2: Difference between groups A/B. Source: Krajinčák E 2024.

The graph illustrates the percentage differences between Group A and Group B for the individual questionnaire items. In all eight questions, Group A achieved higher values of correct or agreeing answers, with differences ranging from 7 to 9%. The most pronounced difference was recorded for questions 4, 5, and 6, where Group A achieved a success rate

higher by 9%. These results suggest that pupils in Group A had a better understanding of, or a more positive attitude towards, the monitored areas after completing instruction with microcontrollers. Overall, the graph confirms that the experimental group achieved consistently better results across all questionnaire items.

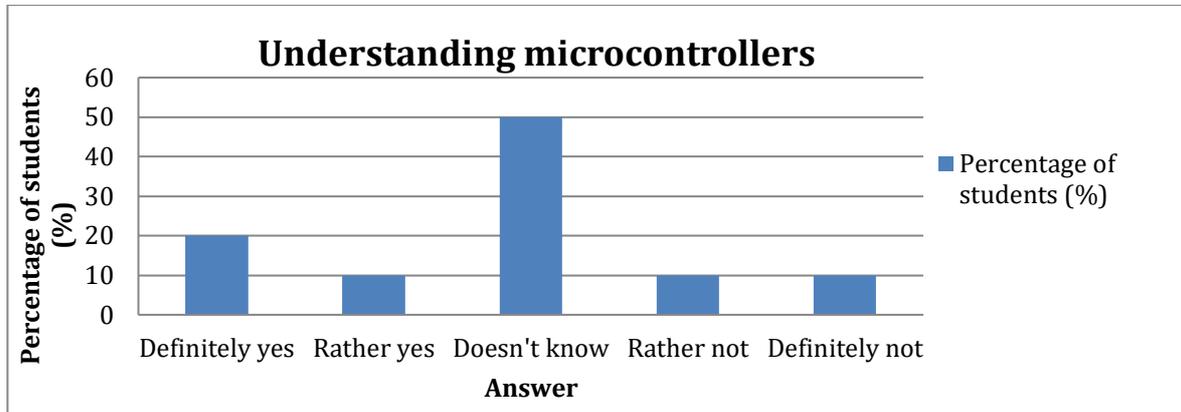


Figure 3: Understanding microcontrollers. Source: Kovács B 2024.

The graph illustrates the level of pupils’ knowledge about microcontrollers before the practical activities were carried out. The results indicate that as many as 50% of pupils chose the answer “Don’t know”, which suggests that the term microcontroller was unfamiliar to them prior to instruction. Only 20% of pupils answered, “Definitely yes” and 10% “Rather yes”, which together represents 30% of pupils with at least partial knowledge in this area. A further 20% of pupils (“Rather no” and “Definitely no”) confirmed that they had not encountered microcontrollers before. The results point to a low initial level of knowledge of the issue, which underlines the need to incorporate microcontrollers into technology and informatics teaching already in earlier grades.

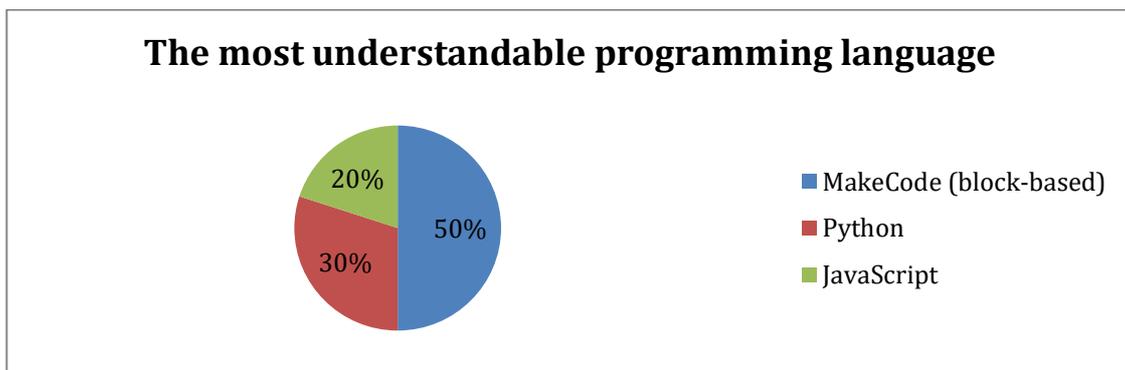


Figure 4: The most understandable programming language. Source: Kovács B 2024.

The graph illustrates which programming language pupils considered the most understandable when working with microcontrollers. Most pupils (50%) indicated block-based programming in the Make Code environment as the clearest and easiest to understand, as it

is visual and intuitive. 30% of pupils preferred Python, which points to growing familiarity with text-based programming. The remaining 20% chose JavaScript, which is less frequently used in the educational environment of primary and secondary schools. The results confirm that block-based environments such as Make Code are the most suitable pathway for beginners to understand the basics of programming microcontrollers.

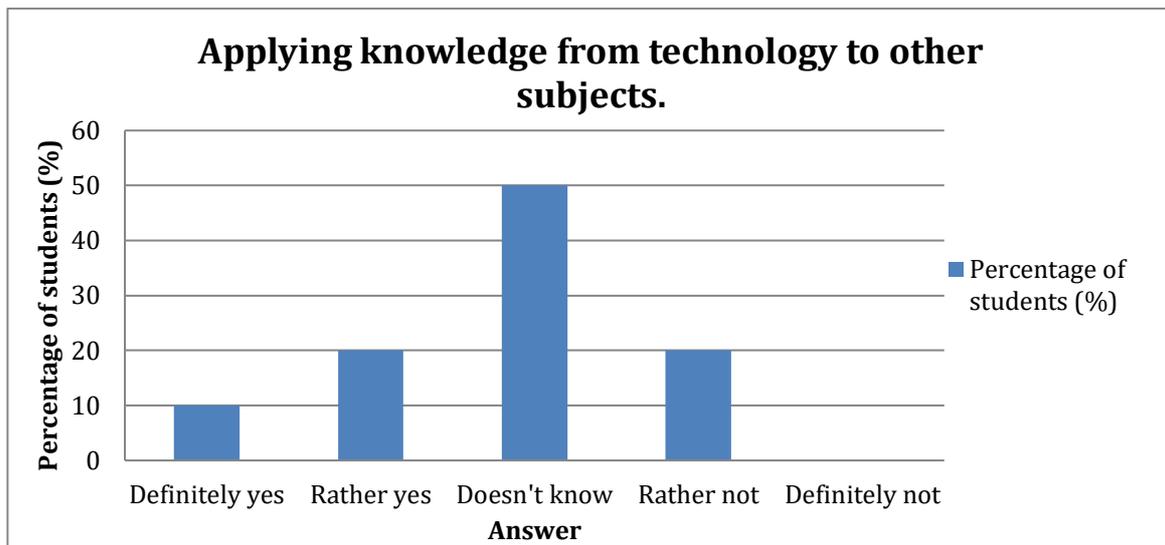


Figure 5: Applying knowledge from technology to other subjects. Source: Kovács B 2024.

The graph illustrates the extent to which pupils perceive the possibility of using knowledge from the subject Technology in other areas of instruction. The largest proportion of pupils (50%) answered “Don’t know”, which indicates uncertainty when it comes to linking content from Technology with other subjects. A further 20% of pupils chose “Rather yes”, while the same proportion (20%) answered “Rather no”. Only 10% of pupils are convinced that they can actively apply what they learn in Technology in other subjects. The results point to the need for stronger cross-curricular integration and systematic support for teachers in designing interdisciplinary tasks that enable pupils to practically apply technical knowledge also in science and informatics subjects.

4 Conclusion

Microcontrollers have become an integral part of modern life, embedded within almost every electronic device encountered daily. Despite their ubiquity in items ranging from mobile telecommunications hardware to household appliances, their presence often remains unnoticed by the end-user. Today, it is rare to find a functional electronic device that does not rely on a microcontroller for its operation. Our investigation into the integration of microcontrollers within the educational process was prompted by several factors. Principal

among these is their compact dimensions and low power consumption, which render them ideal for portable or energy-constrained applications. From an economic perspective, a significant advantage lies in their ability to integrate input/output functions and memory onto a single board; this results in greater efficiency and cost-effectiveness compared to alternative microprocessor systems.

Drawing upon the analysis and implementation of educational activities using microcontrollers in educational practice, we identified several key advantages and potential areas for improvement. It is important to continue developing and innovating in the field of technical education to effectively prepare future generations for the challenges of the digital world.

The results of the analysis, interpreted through the presented figures, offer an overview of the outcomes achieved during the investigation. The displayed data show the basic differences between the groups, the time required to complete the activities, and pupils' responses to individual questions. The results serve primarily as illustrative support for the presented data and help to complement the overall picture of the implemented activities. On this basis, it is possible to create a general comparison of the monitored variables, while a more detailed evaluation would require further research and more extensive processing.

The research findings can serve as a valuable source of information and inspiration for teachers interested in integrating technologies into the educational process and supporting interdisciplinary relationships. Future studies could broaden understanding and inform the design of optimal ways of using microcontrollers in various educational contexts, thereby contributing to further development in this area. Developments in the field of microcontrollers are advancing rapidly, both in terms of hardware and software.

For this reason, microcontrollers are increasingly being integrated into the educational process already at primary schools, especially at the lower secondary level. Pupils often do not perceive microcontrollers merely as educational tools, but rather as devices capable of enhancing their daily lives. Research has demonstrated that the integration of microcontrollers into the curriculum significantly bolsters pupils' motivation. Furthermore, these tools can be effectively utilised to facilitate cross-curricular links, serving as a practical medium for implementing interdisciplinary education.

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